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Dr. Beck and Professor Washburn commented upon the Jury system, as to its origin, character, and relations to the analogous institutions in ancient Greece and Rome.

Mr. Folsom pointed out the origin and history of the line,

"Flos rubet, inque auras frustra disperdit odorem,"

which Gray had been thought by some to have plagiarized.

Five hundred and twentieth Meeting.

April 14, 1863. — MONTHLY MEETING.

The PRESIDENT in the chair.

The Corresponding Secretary read various letters relative to the exchanges of the Academy.

Also a letter from Professor Christopher Hansteen of Christiania, Norway, in acknowledgment of his election as a Foreign Honorary Member.

Mr. Alexander Agassiz read a paper, of which the following is a summary: —

On the Embryology of Asteracanthion berylinus Ag. and a species allied to A. rubens M. T. Asteracanthion pallidus Ag.; by A. AGASSIZ.

The following account of the development of our common star-fishes is intended to appear in full, with many plates, in the fifth volume of the Contributions to the Natural History of the United States of Prof. Agassiz. A part of the material for the investigation was obtained by artificial fecundation, and the rest by fishing for it with the dip-net during the greater part of the summer of 1862.

The larvæ of our common star-fishes are found floating in large numbers at night among those long trains of cast-off skins of barnacles collected by the tide, which appear to provide them, as well as many of our small crustacea, hydroids, and annellids, with food during the time when they swim freely about. They seem to be nocturnal, as I have only found here and there a single specimen when fishing for them in the daytime under exactly the same circumstances of tide and wind.

The adult larvæ move about quite rapidly by means of the cilia of their vibratile chord. Their position in the water is much more con-

stant than when young. The anal portion is kept in advance when moving, and the larva rotates about, but not as frequently as when young; moving more generally with either the ventral or dorsal side uppermost, and more rarely in such a way that the profile can be seen. When at rest, they invariably assume one and the same position; that is, turn slightly obliquely below the anal portion, with the dorsal surface downwards. In this way they often remain for a long period, simply carried about by the currents; the only movements being the expansion and contraction of the œsophagus, and the slow bending and twisting of the arms in every direction.

Up to the stage represented in Fig. 9, all the larvæ were raised by artificial fecundation from eggs of *Asteracanthion berylinus Ag.* At the time when I discovered these larvæ I immediately examined the ovaries of our star-fishes, and found that in one species, the *berylinus*, the eggs were not yet sufficiently advanced to be fecundated, while the eggs of the second species, which is so common on our rocks, the *Ast. pallidus*, had all escaped. I had, however, been fortúnate enough to find quite young larvæ of this second species in which the water-tubes were still exceedingly small, and had made a complete series of drawings of general outlines from their youngest stage up to the time when the star-fish is formed, so that I am certain that all the young I have represented as belonging together are those of one species, as the interval between the time when these two species spawn is more than three weeks.

The time of spawning is very short; three or four days after the *Ast. berylinus* began to spawn it was quite difficult to find females which had not lost their eggs, and a week after that period I found none. Owing to this great difference in the time of spawning, and its short duration, the dates at which I caught these star-fish larvæ floating about leave no doubt to which of the species the larvæ belonged. A careful comparison of the youngest specimens also shows very striking differences, which will always enable an observer to distinguish readily the larvæ of these two species, even in their earlier stages.

The males can easily be distinguished from the females by their difference of color; the females being always slightly bluish, while the males have a decidedly reddish tint. The same difference in color is noticed in our Sea-urchin, *Toxopneustes drobachiensis.* The females are of a light green at the time of spawning, while the males are of a dull vermilion color.

In eggs which have been fecundated artificially (Fig. 1), the spermatic particles surround like a halo the whole of the outer envelope, beating about its surface with the greatest violence. The yolk soon begins to contract after the germinative vesicle and dot have disappeared, and then divides into two spheres. (Fig. 2.)

The segmentation takes place very rapidly, and as soon as there are eight spheres (Fig. 3), they arrange themselves in such a manner as to enclose the remaining space, which is more and more separated as the spheres become more numerous; finally, there is a complete envelope formed before the young makes its escape from the egg.

The young when it escapes is spherical. The walls of the envelope are of the same thickness. One side becomes thicker (Fig. 4); the embryo flattens on the thick side. This wall is then bent in so as to form a slight cavity, in which fluid circulates. (Fig. 5.) This cavity extends half the length of the larva (Fig. 6), then swells at the extremities. The walls become thinner; the pouch formed at the end of the cavity develops laterally to form two smaller pouches (Fig. 7), which soon become small hollow bodies entirely separated from the main cavity. (See Fig. 10.) The main cavity bends slightly to one side (Fig. 8), and eventually forms a junction with a depression opposite to it, and there the mouth is formed. The other opening, which was the first to be developed, thus becomes the anus.

This bent tube divides into three distinct regions, forming the œsophagus, the digestive cavity, and the alimentary canal. (Fig. 9.)

The small hollow bodies, the water-tubes, which are not connected with one another in the young embryos (Fig. 10), differ one from the other. One, the left (when seen from above), connects with the surrounding medium by means of an opening, the water-pore. (Fig. 9.) In older specimens these two tubes extend to the extremity of the digestive cavity, and towards one another, beyond the mouth, where they unite, forming a Y-shaped tube. (Fig. 11.) Arms are developed which are edged with rows of vibratile cilia. Some of these arms are of a different character, having different appendages (see Figs. 12, 13). On these water-tubes is developed the star-fish; one of the water-tubes (the one with the water-pore) developing the actinal side and the tentacles (Fig. 13), the other developing the spines and the abactinal area (Fig. 12). These opposite parts of the star-fish are open (Fig. 13) pentagonal spiral surfaces, not in the same plane, but making nearly a right-angle with one another. The water-pore becomes the madreporic body.

Fig. 1.

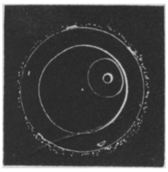


Fig. 2.

Fig. 3.

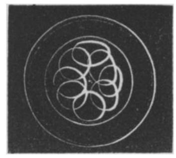


Fig. 4.

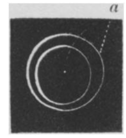


Fig. 7.

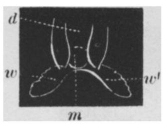


Fig. 8.

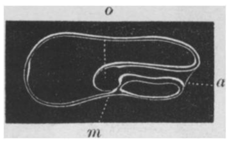


Fig. 6.

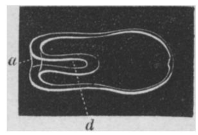


Fig. 5.

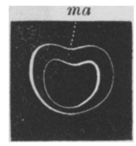


Fig. 9.

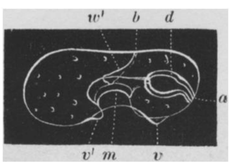


Fig. 12.

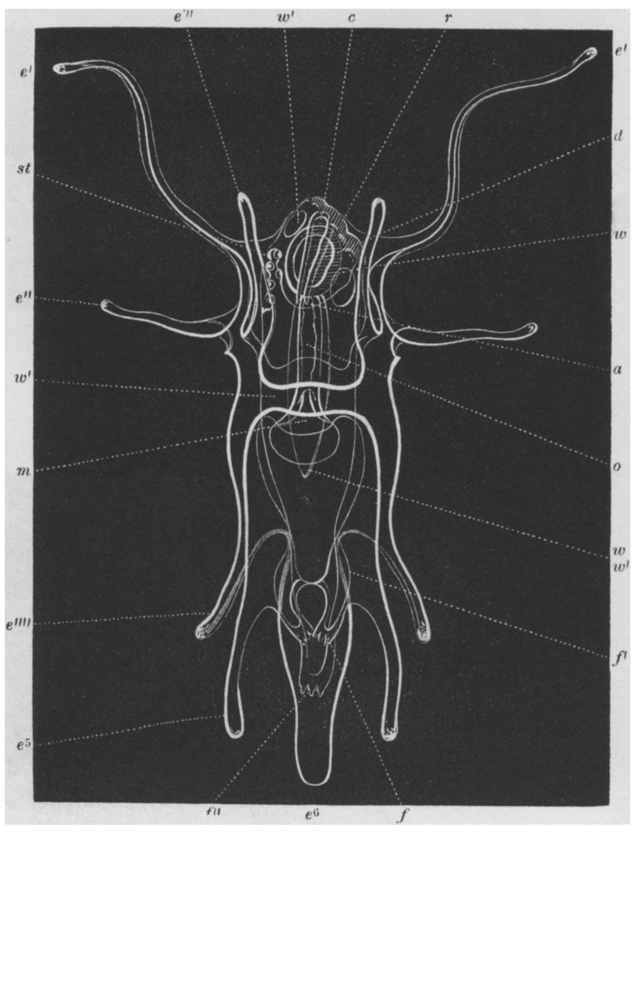


Fig. 10.

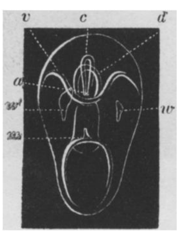


Fig. 11.

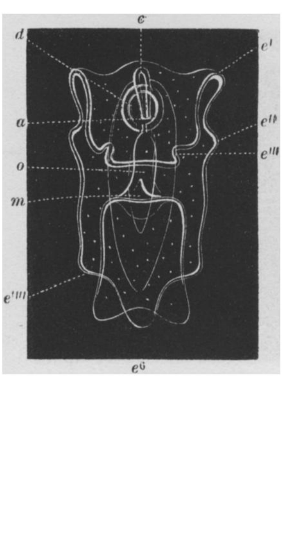


Fig. 16.

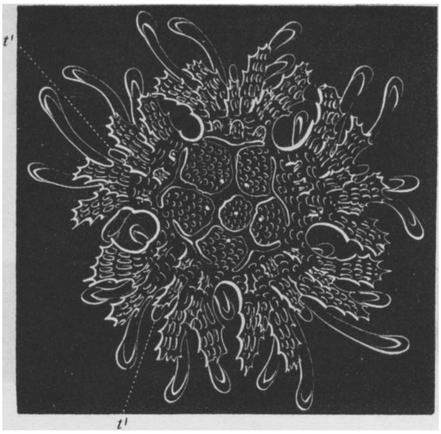


Fig. 14.

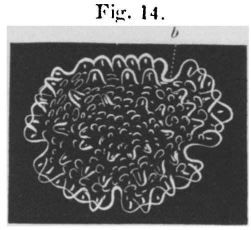


Fig. 15.

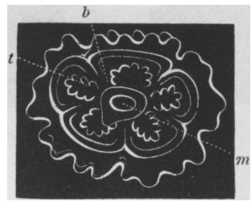


Fig. 18.

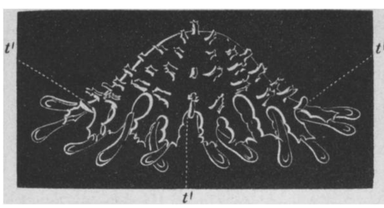


Fig. 17.

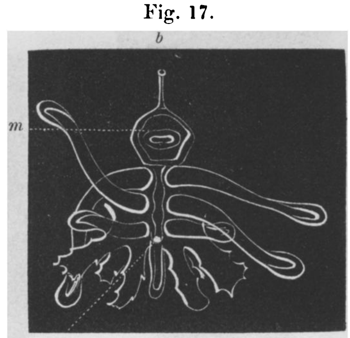
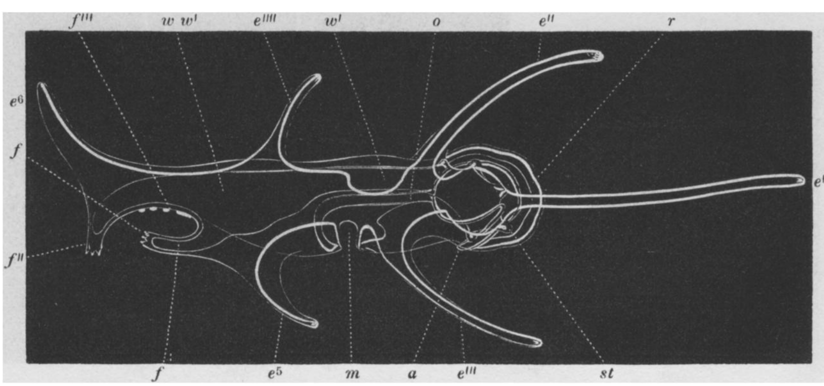


Fig. 13.



The open pentagons do not close till after the star-fish has absorbed the whole of the larva. The complicated system of arms and the whole of the Brachiolaria is absorbed by the star-fish, which is not separated from the larval stock, as seems to be the case in Bipinnaria according to Müller's statements.

The arms of the star-fish are broad and short in the young. (See Figs. 14, 15, 16.) The suckers are pointed, and arranged only in two rows (Fig. 17). The disc is developed only later. The odd terminal tentacle has an eye at its base, and never develops a disc (Fig. 17). The abactinal surface is very arched (Fig. 18). The spines are arranged in regular rows, and the plates remind us of the arrangement of plates of Crinoids (Fig. 16). The anus opens near the edge of the disc on the lower side. The madreporic body also is situated on the edge (Fig. 17).

The mode of development of star-fishes, as observed in our Asteracanthion, cannot be called a case of alternate generation, nor is it a metamorphosis in the ordinarily received sense. It is, in fact, a mode of development peculiar to Echinoderms, something entirely different from what we find in any other class of Radiates. It is not an alternate generation; for the Brachiolaria can in no way be called a nurse, as each Brachiolaria produces but one star-fish, the whole Brachiolaria being absorbed by the star-fish, and not a single appendage left out. Nor is it a metamorphosis, as the changes which take place are so gradual, that at no time can the line of demarcation be drawn between two stages, with any degree of precision, as in Crustacea or Insects. It is a mode of development eminently Echinodermoid, and whether we observe it in the Ophiurans, the Sea-urchins, the Holothurians, or the Crinoids, there seems no doubt, from the observations of Müller, that it takes place according to one and the same plan.

Lately there has been a great deal of discussion among the writers on Echinoderms, as to whether the madreporic body was a proper point to start from to draw the axes of the body; Agassiz, on one side, maintaining that the madreporic body was constantly in the same relation to the different parts of the Echinoderm; while Müller, Desor, and Cotteau have been the most prominent opponents of this view. The mode of formation of the madreporic body seems to me to decide this question. It is invariably on the left water-tube that we find the madreporic body. While the star-fish is developing, it is placed at the angle of the upper arm, and the natural consequence is, that the madreporic body will invariably be found opposite the middle arm of the

five, when the pentagon has become closed. The opening of the anus, on the contrary, has no such clear and precise position with reference to the odd arm as the madreporic body. At any rate, it is perfectly apparent that the madreporic body is always in the suture of the terminal arms of the pentagon, which places it opposite the odd arm. The case of the Echinometradæ and of Salenidæ is constantly brought up to show that the madreporic body is not connected with any definite axis of the body; but from what has been shown of the twisted state of a young star-fish, and of the manner in which it unwinds itself afterwards, and from the fact that in Echinidæ we find families in which the unwinding is not completed, and the madreporic body naturally cannot be in a line passing through the middle of the animal, though still opposite the odd arm whatever its position may be, owing to this embryonic feature, as in the Echinometradæ, we infer that the madreporic body retains the same normal position in all Echinoderms.

On embryological grounds, from the changes which the young star-fishes undergo, it is evident that all the star-fishes with pentagonal outline and pointed tentacles, like Ctenodiscus, stand lower than star-fishes like Luidia, with elongated arms and pointed tentacles; that pentagonal star-fishes, like Culcita, without any spines or plates, though higher than those just mentioned on account of the discs of the tentacles, stand lower than those pentagonal star-fishes like Hippasteria and Antennea, where we have a complicated system of plates. Next, those star-fishes which have suckers and long, smooth arms, like Ophidiaster, stand lower than those star-fishes which have tentacles provided with suckers, and complicated spines on the surface of their long, slender arms, as Asteracanthion. Finally, as a general rule, all star-fishes with two rows of suckers are lower than those which have four, the former being an embryonic character. Among other characters which are not those of the order, but nevertheless exist in the young star-fish, the most prominent is the position of the madreporic body on the actinal side, which is a feature of the Ophiurans. The position of the anus next to the mouth is eminently crinoidal, as well as the arrangement of the plates on the abactinal side; while the arched abactinal area and the tall spines remind us of the Echinoids.

The mode of development of Echinaster is not according to a different plan; it seems to me to be only a shorter way of arriving at the same result. There is not the same complicated system of arms, as the young is not nomadic, but is carried about by the parent. From

what I have been able to see of the development of our Cribrella, I should think it highly probable that the peduncle is homologous to the brachiolar appendages of the Brachiolaria. I would also suggest that the two modes of development, the viviparous and plutean of the Ophiurans, and the auricularian and the other mode of growth of the Holothurians, do not differ in any other way, and that future investigations will show that in all these cases the young Echinoderm is developed from the water-tubes, whether it is a nomadic or plutean mode of development, as I shall call it, or a sedentary mode of development, as we may call the second, where the eggs are carried about by the parent till the young Echinoderm has passed through the greater part of its development.

The younger stages of the larva of the *Echinus drobachiensis* do not differ, in their general features, from the mode of development of the star-fishes. We have the same water bodies formed as diverticula from the digestive cavity, the same differentiation of the digestive cavity into an alimentary canal, a stomach, and an œsophagus. This differentiation only takes place at an earlier period than in the star-fish, before the mouth is formed. However, there is nothing in the earlier stages of development of the Sea-urchin which is not applicable as well to the Brachiolaria.

Figs. 1 – 9. — *Asteracanthion berylinus.*

Fig. 1. Egg of *Asteracanthion berylinus* Ag., surrounded by spermatic particles during artificial fecundation.

Fig. 2. The yolk has divided into two segments.

Fig. 3. The yolk has divided into eight spheres. We can already see at this early stage the tendency of the peripheric arrangement of the spheres to form an outer shell.

Fig. 4. An embryo hatched from the egg a few hours, showing the difference in the thickness of the walls at the two poles (a).

Fig. 5. The same as Fig. 4, somewhat more advanced; a depression appears at the pole (a) where the thickening of the walls is found. This is the first appearance of a mouth.

Fig. 6. An embryo somewhat more advanced, in which this depression has assumed the shape of a long digestive cavity (d), in which the opening (a) performs at the same time the functions of anus and mouth.

Fig. 7. The extremity of the digestive cavity at the time of formation of the water system, at the moment when the two water-tubes (w, w') are about to separate from the digestive cavity (d), from which they arose as diverticula; they are still united in this figure.

Fig. 8. An embryo somewhat more advanced than Fig. 6, seen in profile, to show that this digestive cavity does not remain in the centre of the body, but bends towards one side, and eventually joins the wall of the lower side as seen here (m). This point of junction is the indication of the future mouth, after the formation of which the first mouth assumes exclusively the functions of an anus, which is also now bent down, while the anal extremity of the embryo (a) is slightly bevelled.

Fig. 9. An embryo of *Asteracanthion berylinus* still more advanced than Fig. 8, seen in profile; at this time the digestive cavity has been differentiated into three distinct parts, — a retort-shaped stomach, of which the bulb is the stomach (d), and the tube the alimentary canal, the walls of which are quite thick, while the walls of the œsophagus are quite thin and transparent, capable at the same time of great contraction and expansion. The mouth (m) is seen like a large opening in the middle of the depression on the lower side, leading into a pistol-shaped œsophagus. Immediately over this is seen one of the water-tubes communicating by means of a tube (w') with the outer medium. This opening (b) becomes eventually the madreporic body. On the opposite side there is a similar water-tube which has no connection with this one, and does not open outward. The two small protuberances (v, v') on the sides of the mouth are the first signs of the chord of vibratile cilia.

Figs. 10 – 18. — *Asteracanthion pallidus.*

Fig. 10. A young embryo of *Asteracanthion pallidus* seen from the mouth side, to show the position of the two water-tubes (w, w'), and also the manner in which the vibratile cilia commence as two independent arcs on each side of the mouth. The broad œsophagus is also seen leading into the round stomach (d), which empties through a narrow alimentary canal (c), through an anus (a) placed near the upper arc of vibratile cilia.

Fig. 11. An embryo in which all the parts of the Brachiolaria can already be detected. (Compare with Fig. 12.) The two simple arcs of vibratile cilia have formed two independent plastrons, the corners and indentations of which are the first traces of the future arms (e', e'', e''', e''''). The two independent water-tubes of the preceding figure have increased in size; they now extend beyond the level of the mouth, and form a broad Y-shaped body, which surrounds the œsophagus (o) and extends from the mouth to the opposite extremity of the stomach.

Fig. 12. A Brachiolaria in which the corners of the vibratile chord of the embryo of the preceding figure have developed into long arms ($e', e'', e'''\ldots$). There are also three small heavy appendages (f, f''), surmounted by short warts, which did not exist in the other figures, situated at the extremity opposite to that where the young echinoderm is developed. Branches of the water system (f') enter into these arms, as shown in the following

figure (Fig. 13), in which the embryo is seen in profile. This figure represents it from the mouth side. We see on the left of the stomach the open curve of the tentacles (*st*), while on the other side the beginning of the abactinal region (*r*) is visible. The tentacles are formed, as is clearly seen in this figure, by the folds of the walls of the water-tube of one side; while the abactinal area (*r*) is developed on the surface of the water-tube placed on the opposite side. The large opening (*w*) on the right of the stomach is a branch of the water system which passes out on the opposite side, under the intestine, between it and the stomach.

Fig. 13 is Fig. 12, seen in profile. It shows the course of the vibratile chord, the position of the rudimentary tentacles (*st*) of the young star-fish, the shape of the œsophagus (*o*) and its position, hanging down between the Y shanks of the water system. The position of the branches of the water system (*f'*) which pass into the brachiolar tentacles is also clearly seen.

Fig. 14 is a young star-fish (*A. pallidus*), a few hours after it has absorbed the Brachiolaria. Its irregular outline is apparent. The arms are not yet all in one plane; the young star-fish is not yet unwound.

Fig. 15. The same as Fig. 14, seen from the actinal side to show the rudimentary character of the tentacles (*t*), which are simple loops opening into a wide cavity. The mouth (*m*) of the young star-fish is movable. In this and the preceding figure the spines are simple warts, with accumulation of Y-shaped limestone particles. They are, however, arranged in regular order; the outer rows of each arm have four spines, the next three, then two, and finally a central one.

Fig. 16. A young star-fish much more advanced than Figs. 14 and 15, in which the arms are on one level, the spines quite well developed, and the tentacles extending far beyond the edge of the disc, provided with suckers. We see in this particularly well the crinoidal arrangement of the plates of limestone particles on the abactinal side. The arrangement of the spines is still regular. There are no signs of the madreporic body or of the anus on this abactinal side.

Fig. 17. The lower side of a young star-fish in about the condition (not quite as advanced) of Fig. 16, to show that the terminal tentacle (*t'*, Fig. 16) never develops a sucker; but at the base of this odd tentacle, which always remains cylindrical, even in the adult, we find an eye-speck (*e*) placed on a prominent bulb. The other tentacles, as is seen in the same figure, have all suckers, and are arranged in one row on each side of the radiating tube. The position of the madreporic body (*b*) is still on the lower side, opening in the angle between two of the arms, as is seen in this figure.

Fig. 18 is a young star-fish seen in profile, to show the arched abactinal area and the mode of carrying the odd ocular tentacle (*t'*), which is always turned up. The spines are very prominent for the size of the star-fish, and in this attitude the young star-fish would readily be mistaken for a young sea-urchin.

Explanation of Lettering.

a, anus.
o, œsophagus.
m, mouth.
d, digestive cavity.
c, alimentary canal.
w, water-tube.
w′, water-tube leading to madreporic body.
w w′, point of junction of *w* and *w′*.
b, madreporic body or suture of the arms.
$e', e'', e''', e'''', e^5, e^6$, arms of Brachiolaria.
f, brachiolar arms.
f″, odd brachiolar arm.
f′, branch of water-tube leading into *f*.
f‴, surface warts of *f″*.
s, actinal region.
r, abactinal region.
t, tentacles.
t′, odd terminal tentacle of star-fish.
e, eye of star-fish.
v, vibratile chord, anal part.
v′, oral portion of vibratile chord.

Professor Peirce and Mr. Winlock made a communication upon the remarkable auroral arch seen on Thursday evening, the 9th instant.

Professor Lovering made the following communication

On the Velocity of Light, and the Sun's Distance.

Foucault's recent experiment on the velocity of light, though of a less popular character than his celebrated pendulum-experiment to prove the earth's rotation, will, nevertheless, attract even more attention among men of science. If its results are placed beyond doubt, they will affect Astronomy to a degree not possible for the pendulum-experiment, unless it had come as early as the time of Galileo. I shall examine Foucault's investigation on the velocity of light: 1st, as it influences the science of Optics; and 2d, as it tells upon one at least of the vexed questions in Astronomy.

In the circle of the sciences the centre may be placed anywhere, and the circumference will be everywhere; such is the natural dependence of each upon all the rest. The child even may become father of the man. After the science of Optics had furnished Astronomy with the telescope, the astronomer discovers with it the satellites of Jupiter and the aberration of light, and with the help of these phenomena assigns the value of the velocity of light, and thus repays to Optics the debt incurred by his own special science. Now for the first time the science of Optics has relinquished the guardianship of Astronomy; ascertained by direct experiment one of its own fundamental data, and thereby, possibly, put Astronomy under a new obligation, to be cancelled doubtless, with interest, hereafter.

Let us glance first at the two astronomical methods of measuring the velocity of light. While the senses of touch and taste act only by contact, those of hearing and seeing bring the mind into communication with distant objects. The air and the omnipresent ether supply the delicate and ever-ramifying threads by which telegraphic intercourse is maintained with the ear and the eye. When the origin of the sound or the light is at a large distance, compared with the velocity of the acoustic or luminous wave, allowance must be made for the time taken by the news of an audible or visible event to come to us. Only the vast spaces of Astronomy are commensurable with the great velocity of light, and furnish a sufficiently large theatre for a direct experiment upon it. But in stellar astronomy the magnificence of the extent of view so far transcends in magnitude even the velocity of light, that the luminous ray, vast as is its speed, seems to loiter upon its long way.

Hence in Astronomy a distinction exists between the *actual* interval of successive events and the *apparent* interval. For example, the first satellite of Jupiter revolves around its primary in about 42½ hours; and, therefore, enters the shadow of Jupiter and is eclipsed once every 42½ hours. As it takes light more than 40 minutes to pass over the average distance of Jupiter, the eclipse is not seen until so many minutes, on the average, after it has happened. If this delay were constant, the interval of successive eclipses would not be changed. But in the course of six months the distance of the earth from Jupiter increases by the diameter of the earth's orbit, and in the next six months changes back again; and when the earth is nearest to Jupiter, the news of an eclipse reaches us in about 32 minutes; whereas if the earth is at the greatest distance, 50 minutes are required. Consequently, the intervals between successive eclipses, as they exist for our eyes, are variable, being sometimes larger and sometimes smaller than the real intervals. This irregularity in the apparent intervals of the eclipses of the same satellite, at first attributed to errors of observation, finally conducted Römer in 1675 to the discovery of the velocity of light. Delambre, after discussing 1000 of these eclipses, observed between 1662 and 1802, calculated the velocity of light to be such as to require 493.2 seconds to pass over the mean distance of the sun. If this time divides 95,360,000 statute miles, which is the sun's distance as given by the transits of Venus in 1761 and 1769 according to Encke's computations, the quotient, or 193350 statute miles, is the velocity of light in a second.

The second process which Astronomy has supplied for obtaining the velocity of light may be called the indirect method. It demands not a *space*, but a *velocity* which is commensurable with the velocity of light. If two such velocities are compounded together, according to the principle of the *parallelogram of motions*, there is a resultant motion, the direction of which deviates sensibly from that even of the largest motion which enters into the composition. In nature the velocity of the earth is compounded, in this way, with the velocity of light, and imparts an apparent path to the light, differing by a small angle from the true path. The angular displacement which this causes between the apparent and real places of a star is called aberration, and was first discovered by Bradley, in 1726; this astronomer explaining, on this simple principle, anomalies in observation which had hitherto been considered accidental. As the displacement of the star works opposite ways at opposite seasons of the year, half the difference between the extreme places is the distance from the apparent to the true place, or the constant of aberration. This, when known as an observed fact, establishes the ratio between the velocity of light and the velocity of the earth, and enables the astronomer to assign the value of the one with all the accuracy which pertains to his knowledge of the other. Accepting Struve's determination of the aberration, viz. $20''.45$, the velocity of light is calculated to be 10088 times as great as the velocity of the earth. The mean velocity of the earth is known with all the certainty which belongs to our knowledge of the magnitude of the earth's orbit; that is, of the sun's distance. Assuming, as before, that the distance derived from Encke's parallax is the most reliable, the velocity of the earth in one second of solar time is 18.987+ miles. This multiplied by the aforesaid ratio gives 191513 miles for the velocity of light by Bradley's method. It appears, therefore, that the velocities by the two methods of Astronomy (the direct and the indirect), differ by 1837 miles; a small quantity comparatively, being only *one per cent* of the whole velocity. Whatever other value is adopted for the sun's distance will alter these two results proportionally, without disturbing the ratio between them. I may add, that the velocity which aberration ascribes to light belongs to it at the earth's surface; that is, in the dense atmosphere; whereas, the velocity discovered from the eclipses is that which extends through the planetary spaces. This distinction, however, will do little towards bringing the two results into greater accordance. The velocities of light in different media are pro-

portional to the indices of refraction inversely, which in the case presented are as 1 to .000294. This theoretical difference of velocities is less than $\frac{1}{3000}$ of the whole, or less than 70 miles.

Compare with these conclusions of Astronomy two experimental results on the same subject. Although Wheatstone's experiment on the velocity of electricity, published in 1834, suggested the possibility of measuring, in a similar way, other great velocities, I shall consider first a contrivance of Fizeau, equally applicable to light and to electricity. If a wheel finely cut into teeth on its circumference is put in rapid rotation, a ray of light which escapes between two consecutive teeth will, after being reflected perpendicularly by a mirror, return to strike the wheel at a different point, and either be intercepted by a tooth, or admitted at another interstice. Suppose the velocity of the wheel just sufficient to bring the adjacent tooth to the position whence the ray first started, in the time which the light occupies in going to the mirror and returning. In this time the wheel has moved over an angle found by dividing 360° by twice the number of teeth which the wheel contains. Therefore the time taken by light in going over a line equal to twice the distance of the mirror is that portion of a second found by dividing unity by the product of the number of turns the wheel makes in a second, multiplied by double the number of teeth on the wheel; the velocity of the wheel being first made the smallest which will cause it to intercept the light. Such an experiment was made in 1849, by Fizeau, the rotating wheel being placed in a tower at Suresne, near Paris, and the mirror upon a hill (Montmartre) at the distance of 8633 metres. As the wheel contained 720 teeth, and the slowest velocity which produced obscuration was 12.6 turns a second, it appeared that light required $\frac{1}{18144}$ of a second to go 8633 metres and return. Hence the velocity was 313,274,304 metres, or 194667 miles a second. The French Academy thought so favorably of this attempt that they referred the subject to a scientific commission consisting of Biot, Arago, Pouillet, and Regnault, with authority to procure a grand machine for repeating the experiment.

When Arago advocated the claims of Wheatstone to the vacant place of corresponding member of the French Academy in the section of Physics, it was objected that Wheatstone had only made a single experiment, without having discovered a principle. Arago engaged to prove that the candidate had introduced a fertile method of experimentation, which would be felt in other sciences as well as electricity.

For example: the corpuscular theory of light requires that the velocities of light in different media should vary directly as the indices of refraction, whereas the undulatory theory inverts this ratio. Arago prepared for the trial by experiments on rapid rotations, the mechanical difficulties to be overcome, and the comparative advantage of slower rotations, assisted by several reflections, in place of a single mirror turning with its maximum speed. Aided by the refined skill of Breguet, he realized velocities in the mirror of 1000 turns a second, and of the axis detached from the mirror of even 8000 turns. In the mean while his eyesight began to fail him, and younger physicists entered into the fruit of his labors. After Foucault and Fizeau by separate efforts had decided the question in relation to the velocities of light in air and in water in favor of the undulatory theory, and thus confirmed a conclusion which Arago reached by *diffraction* in 1838, and after Fizeau had studied the variation of the velocity of light in running water, according as the motions agree or differ in direction, Foucault was emboldened to attempt a measure of the *absolute* velocity of light by an experiment which could be brought within the compass of a single room. I translate his own account of the arrangements made for this purpose: —

"A pencil of solar light reflected into a horizontal direction by a heliostat, falls upon the micrometric mark, which consists of a series of vertical lines distant from one another $\frac{1}{10}$ of a millimetre. This mark, which in the experiment is the real standard of measure, has been divided very carefully by Froment. The rays which have traversed this initial surface fall upon a plane rotating mirror at the distance of a metre, where they suffer the first reflection, which sends them to a concave mirror at the distance of 4 metres. Between these two mirrors, and as near as possible to the plane mirror, is placed an object-glass, having in one of its conjugate foci the virtual image of the mark, and in the other the surface of the concave mirror. These conditions being fulfilled, the pencil of light, after traversing the lens, forms an image of the mark on the surface of this concave mirror.

"Thence the pencil is reflected a second time in a direction just oblique enough to avoid the rotating mirror, an image of which it forms in the air at a certain distance. At this place, a second concave mirror is placed, facing so that the pencil, once more reflected, returns to the neighborhood of the first concave mirror, forming a second image of the mark. This is taken up by a third concave mirror, and so on to the

formation of a last image of the mark on the surface of the last concave mirror of an odd number. I have been able to use 5 mirrors, which furnish a line 20 metres long for the ray to travel.

"The last of these mirrors, separated from the preceding one which faces it by a distance of 4 metres, (equal to its radius of curvature,) returns the pencil back on itself; a condition surely fulfilled, when the returning image and the original image on the last mirror but one coalesce. Then we are sure that the pencil retraces its steps, returns in full to the plane mirror, and all the rays go back through the mark, point for point as they went forth.

"This return of the pencil may be proved on an accessible image by reflecting the pencil to one side by a surface of glass at an angle of 45°, and examining it through a microscope of small power. The latter, resembling in all respects the micrometric microscopes in use for astronomical observations, forms with the mark and the inclined glass one solid piece of apparatus.

"The real image sent into the microscope, and formed by the returning rays, partially reflected, occupies a definite position in relation to the glass and the mark itself. This position is precisely that of the virtual image of the mark, seen by reflection in the glass. At least this is true when the plane rotating mirror is at rest. But when this mirror turns, the image changes its place; for while the light is going and returning between the mirrors, the plane mirror has shifted its position, and the returning rays do not strike at the same angle of incidence as when they left it. Hence the image is displaced in the direction of the rotation; and this displacement increases with the velocity of rotation; it also increases with the length of the route passed over by the rays, and with the distance of the mark from the plane mirror.

"If we call V the velocity of light, n the number of times the mirror turns in a second, l the distance between the plane mirror and the last concave mirror, r the distance of the mark from the turning mirror, and d the observed displacement, we have

$$V = \frac{8 \pi n l r}{d},$$

an expression which gives the velocity of light when the other quantities are separately measured. The distances l and r are measured directly by a rule. The deviation is observed micrometrically; it remains to show how the number of turns of the mirror n is found.

"Let us describe first how a constant velocity is imparted to the mirror. This mirror, of silvered glass, and 14 millimetres in diameter, is mounted directly upon the axis of a small air-turbine of a well-known model, admirably constructed by Froment. The air is supplied by a high-pressure bellows of Cavàillé-Coll, justly distinguished for the manufacture of great organs. As it is important that the pressure should be very constant, the air after leaving the bellows traverses a regulator, recently contrived by Cavàillé, in which the pressure does not vary by $\frac{1}{5}$ of a millimetre in a column of water of 30 centimetres. The fluid flowing through the orifices of the turbine represents a motive power of remarkable constancy. On the other hand, the mirror when accelerated soon encounters in the surrounding air a resistance, which, for a given velocity, is also perfectly constant. The moving body placed between these two forces, which tend to equilibrium, cannot fail to receive and to preserve a uniform velocity. Any check whatever, acting upon the flow of the water, allows this velocity to be regulated within very extensive limits.

"It remains to estimate the number of turns, or rather to impress on the moving body a determined velocity. This problem has been completely resolved in the following manner. Between the microscope and the reflecting glass, a circular disk is placed, the edge of which, cut in fine teeth, encroaches upon the mark and partly intercepts it. The disc turns uniformly on itself, so that if the image shines steadily, the teeth at its circumference escape detection from the rapidity of the motion. But the image is not permanent; it results from a series of discontinuous appearances, equal in number to the revolutions of the mirror; and whenever the teeth of the screen succeed one another with the same frequency, there is produced on the eye an illusion easily explained, which makes the teeth appear immovable. Suppose, then, that the disk, with n teeth in its circumference, turns once in a second, and that the turbine starts up. If by regulating the flow of air, the teeth are made to appear fixed, we are certain that the mirror makes n turns in a second.

"Froment, who made the turbine, wished to invent and construct a chronometric wheel-work to move the disk. It is a remarkable piece of clock-work, which resolves, in an elegant manner, the problem of uniform motion in the particular case in which there is no work to be done. The success is so complete, that it is my daily experience to launch the mirror with 400 turns a second, and see the two pieces of

apparatus march within $\frac{1}{10000}$ nearly of accordance during whole minutes.

"Notwithstanding the assurance I had gained in the measurement of time, I was surprised to prove in my results discordances, which were out of proportion to the precision of my means of measuring. After long research, I discovered the source of error in the micrometer, which did not allow of the degree of accuracy willingly attributed to it. To meet this difficulty, I have introduced into the system of observation a modification which amounts simply to a change of the variable. Instead of measuring micrometrically the deviation, I adopt for it a definite value in advance; suppose $\frac{7}{10}$ of a millimetre, or 7 entire parts of the image; and I seek by experiment to find the distance between the mark and the turning mirror necessary to produce this deviation; the measures extending over a length of about a metre, the last fractions have a magnitude directly visible, and leave no room for error.

"By this means the apparatus has been purged of the principal cause of uncertainty; henceforth the results accorded within the limits of errors of observation, and the means are settled in such a way, that I am able to assign confidently the new number, which appears to me to express nearly the velocity of light in space, namely, 298000 kilometres in a second of mean time."

This value reduced to statute miles shows that the velocity of light is 185177 miles in a second; which is less by 6336 miles than the velocity for light usually admitted into science, namely, the velocity obtained from the aberration of light. This discrepancy between the result of experiment, and that astronomical determination which comes nearest to it, is three times greater than the variation between the velocity deduced from aberration and that derived from eclipses.

Foucault states that the extreme difference of the results of various trials amounted to only $\frac{1}{100}$ of the whole quantity, and that the mean result can be trusted to the fraction of $\frac{1}{500}$. Moreover, the aberration of $20''.45$, adopted by astronomers, cannot be supposed at fault by more than $\frac{1}{1800}$ of the whole. Neither the velocity by Foucault's experiment, nor the value of aberration, can be charged with a possible error of 3 per cent, or of any error approaching to this large discrepancy. How is the new velocity of light to be reconciled with the old value of aberration? I have said that aberration establishes only the *ratio* between the velocity of light and the velocity of the earth. If this ratio cannot be tampered with, and if one term of it (the velocity

of light) must be diminished by 3 per cent, to suit Foucault's experiment, then we must at the same time diminish the other term (the velocity of the earth) proportionally; and the old ratio will be preserved and the value of aberration will be left unchanged. Is it possible, therefore, that there can be an uncertainty to the extent of 3 per cent in the velocity of the earth ? If so, the tables are turned ; and instead of employing the ratio which aberration supplies to calculate the velocity of light from the velocity of the earth, as the best known of the two, we henceforth must calculate the velocity of the earth from the velocity of light. For Foucault has found the latter by experiment more accurately than Astronomy gives the former. If there is an error of 3 per cent in the velocity of the earth, it is an error in space, and not in time. To diminish the velocity of the earth sufficiently by a change of time would demand an increase in the length of the year amounting to 11 days nearly.

The only other way of reaching the velocity of the earth is by diminishing the circumference of the earth's orbit, and this, if diminished, changes proportionally the mean radius of the orbit; that is, the sun's mean distance. The question, therefore, resolves itself into this. Can the distance of the sun from the earth be considered uncertain to the extent of 3 per cent of the whole distance.

The answer to this question will lead me into a brief discussion of the processes by which the sun's distance from the earth has been determined, and the limits of accuracy which belong to the received value. To see the distance of any body is an act of *binocular* vision. When the body is near, the two eyes of the same individual converge upon it. The interval between the eyes is the little base-line; the angle which the optic axes of the two eyes, when directed to the body, make with each other, is the parallax ; and by this simple triangulation, in which an instinctive geometrical sense supersedes the use of sines and logarithms, the distance of an object is roughly calculated. As the distance of the object increases, the base-line must be enlarged; but the geometrical method is the same, even when the object is a star, and the base of the triangle the diameter of the earth's orbit. Substitute, then, for the two eyes of the same observer the two telescopes of different astronomers, planted at the opposite extremities of the earth's diameter, and any one will understand the principle upon which the binocular eye of science takes its stereoscopic view of the universe, and plunges into the depths of space. In this way it is that the dis-

tance of the sun from the earth is associated with the *solar parallax*, which is the angle between the directions in which two astronomers point their telescopes when they are looking at the sun at the same moment. To know the sun's distance, the astronomer studies the solar parallax. As Kepler's third law establishes a relation between the distances of the different planets from the sun and their periods of revolution, if the astronomer finds either distance by observation, the others can be computed from this law. As the horizontal solar parallax is only about 8 seconds, and an error of $\frac{1}{10}$ of a second includes an error of more than a million of miles in the sun's distance, he takes advantage of the law of Kepler, and selects a planet which comes occasionally nearer to the earth than the sun. The choice lies between Venus at inferior conjunction and Mars at opposition. The parallax of Mars may vary from 20″.7 to 19″.1, according to the positions of Mars and the Earth with respect to the perihelion of the orbit, at the time of opposition. The parallax of Venus at conjunction may vary, for the same reason, from 33″.9 to 29″.9. Venus, therefore, may be nearer to the earth than Mars, and the parallax more favorable. But Venus cannot be seen at conjunction except when its latitude is so small that a transit across the sun's disc occurs. Then the two observers refer its place, not to a star, but to the sun, and the quantity they determine is the difference of parallax between Venus and the sun, which will vary from about 21″ to 25″. Moreover, the difference of parallax is measured, not directly, but through the influence it produces on the duration of the transit at the two stations, and therefore upon a greatly enlarged scale.

What are the results which have been obtained, 1st, by observations of the transits of Venus, and, 2d, by observations of Mars at opposition?

1. Only two transits of Venus have occurred since the time when the sagacious Dr. Halley invoked the attention of posterity to these rare astronomical events, as pregnant with the grandest results to science; viz. those of 1761 and 1769. The astronomers of the last century did not neglect the charge which Halley consigned to them. The transit of 1769 was eminently favorable, offering a chance which comes only once in a millennium, as Professor Winthrop happily explained in his lectures on the last transits.

Whatever verdict posterity shall pronounce on the deductions from the observations then made, they will never, says Encke, reproach

astronomers or governments with negligence, or want of appreciation towards this golden opportunity. The solar parallax which Encke deduced from an elaborate discussion of all the observations, fifty years after they were made, is 8″.57116. This corresponds to a solar distance of 95,360,000 statute miles.

Although transits of Venus will take place in 1874 and 1882, and astronomers already begin to talk of preparing for them, I have the authority of Encke for declaring that, in comparison with that of 1769, the next two transits will be so unfavorable, that nothing short of perfection in the construction of instruments, and in the art of observing, can compensate for the natural disadvantage; — so that the reduction of the possible error in the sun's parallax within the limit of the hundredth of a second is hopeless for at least two centuries more.

2. The solar parallax may also be derived from the parallax of Mars, when this planet is in opposition. In 1740, the French astronomer, Lacaille, was sent to the Cape of Good Hope, and from the parallactic angle observed between the direction of Mars, as seen from that station and from the Observatory of Paris, deduced from observations of declination, the horizontal parallax of Mars was computed, and consequently that of the sun. The solar parallax thus found was 10″.20, with a possible error not exceeding 0″.25. Henderson, by comparing his own observations of the declination of Mars at its opposition in 1832, with corresponding observations at Greenwich, Cambridge, and Altona, computed the solar parallax at 9″.028.

The United States Naval Astronomical Expedition to Chili, under the charge of Lieutenant J. M. Gilliss, during the years 1849–52, had for its object the advancement of our knowledge of the solar parallax, partly by observations of Mars at opposition, and partly by observations of Venus during the retrograde portion of her orbit, and especially at the stationary points, in conformity with a method suggested by Dr. Gerling; the whole to be compared with simultaneous observations at the northern observatories. Although the observations at Chili were made on 217 nights, covering a period of nearly three years, the co-operation of northern astronomers was so insufficient that only 28 corresponding observations were made. On this account the second conjunction of Venus was useless; the other conjunction of Venus and the second opposition of Mars were of little value, and

even the first opposition of Mars led to no significant result. Dr. B. A. Gould has computed the solar parallax from the first opposition of Mars, observed at Chili, at $8''.50$.

3. The solar parallax can also be computed from the law of universal gravitation. The principle may be thus stated: The motion of the moon round the earth is disturbed by the unequal attraction of the sun on the two bodies. The magnitude of the disturbance will be in some proportion to the distance of the disturber, when compared with the relative distance of the two disturbed bodies; and this ratio of distances is the inverse ratio of the parallaxes of the sun and moon. By selecting one of the perturbations in the moon's longitude particularly adapted to this purpose, Mayer, as early as 1760, computed the solar parallax at $7''.8$. In 1824, Burg calculated this parallax, from better observations, at $8''.62$. Laplace gives it at $8''.61$. Fontenelle had said that Newton, without getting out of his arm-chair, found the figure of the earth more accurately than others had done by going to the ends of the earth. Laplace makes a similar reflection on this new triumph of theory. "It is wonderful that an astronomer, without going out of his observatory, should be able to determine exactly the size and figure of the earth, and its distance from the sun and moon, simply by comparing his observations with analysis, the knowledge of which formerly demanded long and laborious voyages in both hemispheres. The accordance of the results obtained by the two methods is one of the most striking proofs of universal gravitation." Pontecoulant makes the solar parallax by this method $8''.63$. Lubbock, by combining Airy's empirical determination of the coefficient with the mass of the moon, as he finds it from the tides, (namely, $\frac{1}{67}$,) makes the solar parallax $8''.84$. If the mass of $\frac{1}{75}$ is substituted, the parallax is changed to $8''.81$. Finally, Hansen, in his new Tables of the Moon, adopts $8''.8762$ as the value of the solar parallax. Moreover, Leverrier, in his "Theory of the Apparent Motion of the Sun," deduces a solar parallax of $8''.95$ from the phenomena of precession and nutation.

The conclusions of this whole review are summed up in the following table, in which the values of the solar parallax, and of the sun's distance by the three methods of Astronomy, and by the experiment of Foucault, are placed in juxtaposition. Also the different velocities of light found by astronomical observations and by experiment.

Observer or Computer.	Method.	Parallax.	Distance.
		"	Miles.
Encke,	By Venus (1761),	8.53	95,141,830
Encke,	" (1769),	8.59	95,820,610
Lacaille,	By Mars,	10.20	76,927,900
Henderson,	"	9.03	90,164,110
Gilliss and Gould,	"	8.50	96,160,000
Mayer,	By Moon,	7.80	104,079,100
Burg,	"	8.62	94,802,440
Laplace,	"	8.61	94,915,970
Pontecoulant,	"	8.63	94,689,710
Lubbock,	"	8.84	92,313,580
Lubbock,	"	8.81	92,652,970
Hansen,	"	8.88	91,861,060
Leverrier,	"	8.95	91,066,350
Foucault,	By Light,	8.86	92,087,342
Fizeau,	"	8.51	96,117,000
Velocity of Light,	By Eclipses,		193,350
"	By Aberration,		191,513
"	By Fizeau's Experiment,		194,667
"	By Foucault's Experiment,		185,177

Foucault's experiment on the velocity of light has been popularly announced as making a "revolution in astronomical science." But it appears from the preceding sketch, that it has raised no new question in Astronomy, though it may have attracted popular attention to an old difficulty, and possibly given a solution to it. The three astronomical methods present solar distances, which, even if we select the most trustworthy decision of each, differ by three or four millions of miles; that is, by three or four per cent of the whole quantity. Though the best products of the first and second methods were at one time within a million of miles of each other, an increase of lunar observations, and especially improvements in the lunar tables, have now carried that difference up to four millions of miles. If Foucault's experiment were allowed to give the casting vote, it would decide in favor of the third method; thus making the reflection of Laplace, which I have already quoted, still more memorable.

In regard to the commonly received distance of the sun, which is based upon Encke's profound discussion of all the observations made at the last two transits of Venus, the case stands thus: Encke decides from the weights of the observations, discussed in the light of the mathematical principle of *Least Squares*, that the probable error of the sun's distance, as given by the transits, does not exceed $\frac{1}{230}$ of the whole

quantity. Astronomers have also reason to believe that the adopted value of aberration is correct within $\frac{1}{1800}$ of the whole quantity. Moreover, Foucault is confident of his determination of the velocity of light within $\frac{1}{600}$ of the whole quantity; nay, he expects to improve his instruments so as to banish all errors larger than $\frac{1}{6000}$ of the whole quantity. Neither the velocity of light, aberration, nor the sun's distance, can be suspected of an error to the extent of three or four per cent, and yet one at least must be wrong to this degree, as the best values of the three elements are irreconcilable with each other. Which shall be changed?

It may excite surprise in those who have heard of the *accuracy* of Astronomy without weighing the exact significance of the word as applied to so large a subject, that there should still be a lingering uncertainty to the extent of three or four millions of miles in the sun's distance from the earth. But the error, whatever it is, is propagated from the solar system into the deepest spaces which the telescope has ever traversed. The sun's distance is the measuring-rod with which the astronomer metes out the distances of the fixed stars, and the dimensions of stellar orbits. An error of three per cent in the sun's distance entails an error of three per cent in all these other distances and dimensions. Trifling as three per cent may seem, the correction runs up to 600000 millions of miles in the distance of the nearest fixed star.

Five hundred and twenty-first Meeting.

May 12, 1863. — Monthly Meeting.

The President in the chair.

The Corresponding Secretary (who also acted as Recording Secretary in the absence of the latter officer) read letters relative to the Academy's exchanges; also a letter from W. W. Story, Esq., now at Rome, in acknowledgment of his election as a Fellow.

Mr. Treadwell read a memoir on the effect of cannon-shot upon iron-clad ships and armor-plates generally; this being a sequel to his memoir "On the Practicability of constructing Cannon of Great Caliber," published in the sixth volume of the Academy's Memoirs (1856); the object of this sequel